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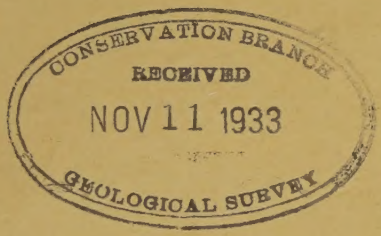
GUIDEBOOK 13 - - - EXCURSION C–1

WESTERN TEXAS
AND
CARLSBAD CAVERNS



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Guidebook 13: Excursion C-1

WESTERN TEXAS
AND
CARLSBAD CAVERNS

By
N. H. DARTON AND P. B. KING
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This guidebook is the result of contributions by N. H. Darton and Philip B. King, of the United States Geological Survey, and B. R. Haigh, of the University of Texas. Mr. Darton wrote the parts relating to the Guadalupe Mountains, Carlsbad Caverns, and the El Paso region, and Mr. King is responsible for details in the Marathon and Glass Mountains, Diablo Plateau, and Hueco Mountains.

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WESTERN TEXAS AND CARLSBAD CAVERNS

By N. H. Darton and Philip B. King

SOME GENERAL FEATURES OF WESTERN TEXAS

The portion of Texas west of the Pecos River is generally known as trans-Pecos Texas. It consists of wide, high plateaus and of mountains made up of tilted and folded sedimentary strata and volcanic rocks. Many of these features have been outlined by relatively recent movements, their details having been subsequently developed by erosion. Most of the mountain ranges have a northwesterly alinement. The climate is semi-arid, but the rainfall is sufficient to maintain a few streams that flow into the Rio Grande, which empties into the Gulf of Mexico. This river, which at most times is only a small, muddy stream, crosses a succession of desert basins and cuts through the separating mountain barriers in narrow and imposing canyons. Salt Basin,[1] a large elongate basin behind and parallel to the Front Ranges, has no exterior drainage. It probably is a graben filled by mountain waste, with playas and salt lakes in its lowest parts.

The mountains of trans-Pecos Texas are barren of timber except on their higher summits, and on most of them there is only a sparse growth of juniper and piñon. In some protected valleys there are small groves of live oak and manzanita, and the few running streams are shaded by cottonwoods. On the lower mountain slopes and rocky foothills there are various cacti, ocotillo, maguey, and other desert plants. Terraces and fans of limestone gravel and the rocky slopes of the mountains support much sotol and lechuguilla. The plains between the mountains are mostly smooth and sparsely grass-grown, with yuccas and greasewood or creosote bushes. Mesquite and catclaw abound in the low places where ground water is near the surface.

Except near El Paso, western Texas has been settled for only about 65 years. Before that time it was ranged over by nomadic

[1] This is not to be confused with the synclinal area east of the Pecos River, in which are salt deposits of Permian age, which has sometimes been called the "salt basin."

Apache and Comanche Indians. Other inhabitants in the earlier days were the Mexicans, who had a few fortified settlements along the Rio Grande and have given the region many of its local names and traditions. Several of the modern highways follow ancient trails used by American caravans and at an earlier time by war and raiding parties of the Indians. Since white settlement the country has been divided into vast ranges used for grazing. Cattle thrive on the grassy plains where water is supplied by windmills and earth storage tanks. Sheep and goats are pastured on the mountainous tracts, because they can climb and graze over steep slopes that are less accessible to cattle.

Most of the southwestern part of trans-Pecos Texas is composed of tilted and flexed Cretaceous strata overlain by remnants of volcanic rocks. In the western part (Quitman and Eagle Mountains), where the Cretaceous succession is very thick and the Jurassic also is present, the rocks are greatly folded and have been shoved northeastward along several large overthrust faults. East of the disturbed area the Cretaceous limestones lie nearly flat and form table-lands, intricately carved by canyons, constituting the Edwards Plateau. In the Marathon region there is a dome from which the Cretaceous cover has been removed by erosion, revealing a thick successsion of Paleozoic rocks with an intensely folded structure of northeasterly trend, imposed on the strata during Carboniferous time.

North of the ranges of folded Paleozoic and Cretaceous strata the surface rocks are mostly Paleozoic limestones and sandstones, not greatly flexed, resting on pre-Cambrian schists and steeply inclined strata of probable Algonkian age. Here are broad block mountains and level plateaus, separated by desert basins, the largest of which is Salt Basin. On the east side of Salt Basin are the Guadalupe, Delaware, and Apache Mountains, in which the strata are mainly tilted to the east. To the west is the Diablo Plateau, which extends 100 miles (161 kilometers) to the next desert plain, the Hueco Bolson, beyond which is the high narrow ridge of the Franklin Mountains.

In this excursion, attention will be given chiefly to the structure, stratigraphy, and fossils of the Paleozoic rocks. The disturbed strata of the Marathon geosyncline on the south will be visited first, and then their flat-lying equivalents in the northern part of the province will be crossed. The excursion begins at Van Horn, a village on the Texas & Pacific Railway near the south end of Salt Basin, almost surrounded by mountains that rise in steep escarpments above the plains. (See fig. 1.)

VAN HORN TO MARATHON

Van Horn to Kent (35 miles, or 56 kilometers).—From Van Horn eastward the highway crosses the desert plain of the Salt Basin. At the south end of this basin, a few miles beyond the road, is the low, dissected range of the Wylie Mountains, made up of limestones of Permian age,[2] with underlying pre-Cambrian schists outcropping along their west end.

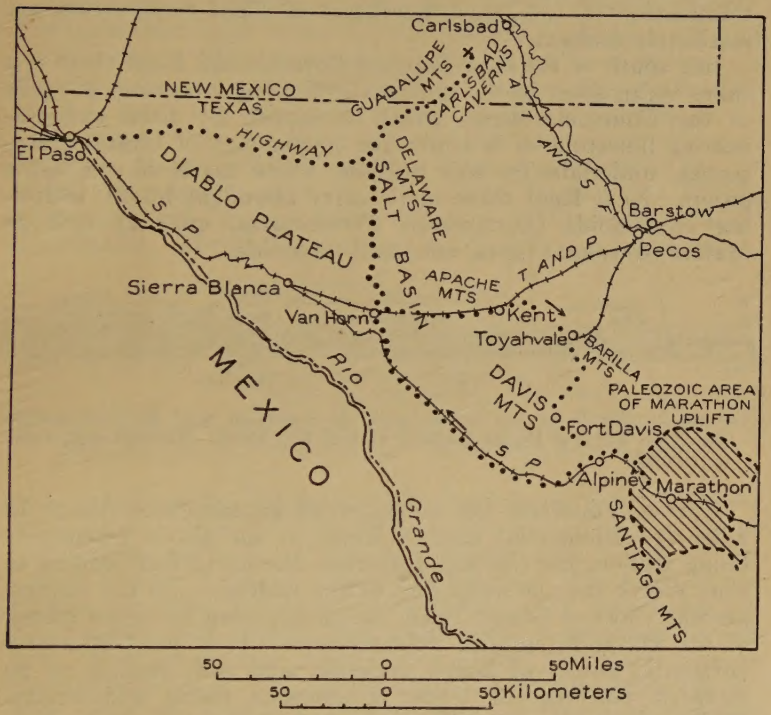

FIGURE 1.—Route map, excursion to western Texas and Carlsbad Caverns

Near Plateau, 18 miles (29 kilometers) east of Van Horn, are buttes and other exposures of sandstone of the Trinity group (Comanche series, Lower Cretaceous), north and south of the highway. Along the southern sky line is a panorama of the

[2] The Pennsylvanian-Permian boundary has not been satisfactorily determined at some places in western Texas. Permian is used here for a thick series of strata carrying late Carboniferous fossils which is separated by a great unconformity from the underlying rocks. The upper part of the underlying series contains typical Pennsylvanian fossils.

northward-facing cliffs of the Davis Mountains, made up of a thick succession of Tertiary volcanic rocks. To the north of these cliffs are lower scarps and benches of the underlying Cretaceous rocks. On the north side of the road there is a gradual rise to the crests of the Apache Mountains, a southward-tilted fault block, with a steep escarpment facing to the north. They consist of reef limestone of Permian age, probably the Delaware Mountain formation. (See fig. 2.) Near the eastern termination of the range, northeast of Kent these strata are intricately faulted.

Just south of the road between Boracho and Kent there is a sharp escarpment in the southward-dipping succession of rocks of the Comanche series which is capped by hard rudistid-bearing limestone of Washita age (upper part of Lower Cretaceous), underlain by soft brilliant white marls of the same group. Near Kent these marls carry abundant fossils, including ammonoids (*Desmoceras*, *Pervinqueria*, etc.) as well as oysters (*Gryphaea navia*, etc.) and echinoids.

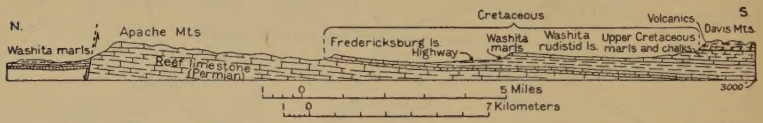

FIGURE 2.—Sketch section across route of excursion near Boracho section house, on Texas & Pacific Railway east of Van Horn. Vertical scale twice horizontal

Kent to Toyahvale (30 miles, or 48 kilometers).—About 12 miles (19 kilometers) east of Kent, at the Davis Mountains filling station, the highway branches, the north fork leading to Fort Worth and the south fork to San Antonio. In the vicinity are fine views of Gomez Peak, the culminating northeast corner of the Davis Mountains volcanic area. It is built of nearly horizontal sheets of latite, andesite, and tuff, resting on an elevated platform of Upper Cretaceous marls and chalks. White outcrops on the slopes of the peak are tuffs in the volcanic series and chalky beds of the Cretaceous. In sandstones intercalated in the lower part of the volcanic series C. L. Baker has recently found teeth and bone fragments of *Hyracodon*, an ungulate of Oligocene age. Near the road forks there has been intricate faulting, by which strata as young as the Taylor marl (high Upper Cretaceous) were dropped on the west side against limestone of Washita age (upper part of Comanche series), which makes the high mesa east of the filling station.

The road to Toyahvale crosses rolling hills of limestones of the Washita group, Eagle Ford flags (Upper Cretaceous), and vol-

canic rocks of Tertiary age. The escarpments of the Davis Mountains are conspicuous to the south. Twelve miles (19 kilometers) southeast of the road forks is the spring of Phantom Lake, on the edge of the highway, which issues from limestones of the Washita group with a flow of 14 second-feet. At Toyahvale is the great San Solomon Spring, on the right of the road, with a flow of 30 second-feet, which is used to irrigate the Balmorhea farming district, to the east.

Toyahvale to Fort Davis (30 miles, or 48 kilometers).—At Toyahvale the route leaves the San Antonio highway and turns south into the Davis Mountains, which have been in view to the south almost since leaving Van Horn. One of the first features is the outlying lava mass of the Barilla Mountains.

Passing around the north end of these mountains the road turns southeast for a few miles up a broad synclinal valley, in which the volcanic series is flexed down between the Barilla Mountains and the main lava plateau of the Davis Mountains. (See fig. 3.) The road then turns to the right, up Limpia Can-

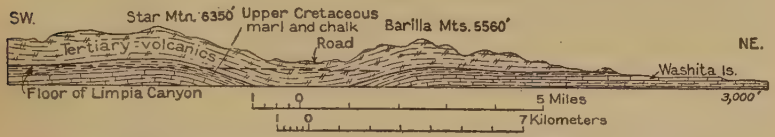

FIGURE 3.—Sketch section parallel to route of excursion in the region of Limpia Canyon, south of Toyahvale. Vertical scale twice horizontal

yon, a steep-walled gorge carved in the volcanic series. Southwest of the synclinal valley the volcanic rocks rise in a broad arch under Star Peak, which brings Taylor marl (Upper Cretaceous) to view in the bottom of the canyon. The walls of the canyon are cliffs of red-weathering latite, with remarkable columnar structure, interbedded with layers of agglomerate and tuff. Because of their altitude the Davis Mountains receive more precipitation than the lowlands of the trans-Pecos region. The mountain sides are wooded, and the fractured volcanic rocks absorb much water, so that there are many springs and streams. Limpia Canyon is famous for the apple orchards that thrive in its wider parts. After crossing the stream many times the road reaches Fort Davis, a village clustering about the old United States Army post, established in 1853, whose adobe walls still stand.

Fort Davis to Alpine (25 miles, or 40 kilometers).—From Fort Davis the road winds across red hills of volcanic rocks to Musquiz Canyon, which, like Limpia Canyon, shows sections of the volcanic flows. Near its mouth, 10 miles (16 kilometers)

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from Alpine, the flows on the west side of the road have been domed by a laccolithic intrusion which protrudes in a rocky peak in the center of the tilted rocks. Near this point is a fine view of Miter Peak, a sharp spine of intrusive rock, probably a volcanic neck.

Alpine to Marathon (28 miles, or 45 kilometers).—Alpine lies in a broad alluvial plain, surrounded by escarpments of the volcanic rocks. The road to Marathon crosses rolling hills of these rocks, and at the summit, 6 miles (9.6 kilometers) east of Alpine, the rugged and dissected north slope of the Glass Mountains comes into view ahead. Many of the ridges are capped by limestones of the Comanche series (Lower Cretaceous), but the lower slopes are Permian dolomite. On the west are other low mountains of Cretaceous and Permian strata, much faulted and cut by intrusives. About 17 miles (27 kilometers) east of Alpine the highway passes around the high west end of the Glass Mountains, and low ridges of older Permian strata come into view ahead. To the east is the steep south face of the main Glass Mountains escarpment, consisting of the Capitan limestone, capping slopes of the Word formation.

At 20 miles (32 kilometers) east of Alpine the highway passes through a broad gap on lower Permian strata and enters the Marathon Basin. In the distance to the south may be seen ridges of white novaculite, the most striking and characteristic of the earlier Paleozoic rocks.

GEOLOGY OF THE MARATHON REGION, INCLUDING THE GLASS MOUNTAINS

General relations.—In the Marathon region the Paleozoic strata have been revealed by the removal of the cover of Cretaceous strata in a broad dome, over an area 30 miles (48 kilometers) in width and 40 miles (64 kilometers) in length. The relatively nonresistant Paleozoic rocks in the center of the dome have been eroded to low mountains and hilly lowlands that form the broad Marathon Basin, which is lower than the surrounding region. To the east and south the basin is rimmed by much dissected table-lands of limestone of Lower Cretaceous (Comanche) age, gently tilted away from the uplift. These table-lands merge eastward into the Edwards Plateau, which extends far to the east and north. On the north rises a low, broad range of northward-tilted Permian rocks, the Glass Mountains, whose bold scarps, capped by limestone and dolomite, face south. On the west the basin is bordered by the narrow and abrupt Del Norte and Santiago Mountains, of sharply upturned limestone (Comanche series). The relief features of the Marathon region

System	Series	Formations, lithology, and fossils	Average thickness		Topography		Geologic and tectonic history
			Feet	Meters			
Cretaceous.	Comanche.	Limestones and marls, overlapping northward on the older rocks. Locally there is a basal sandstone. The limestones contain rudistids, oysters, clams, and gastropods.	1,000 (or less)	305	Flat-topped table-lands with cliffs and benches along their slopes.		Cretaceous rocks are gently folded by movements approximately correlative to Laramide revolution. Formation of a peneplain during first half of Mesozoic.
		Angular unconformity by which Permian is tilted northward as much as 5° more steeply than the Comanche.					
Carboniferous.	Permian.	Bissett formation: Conglomerate and red beds; some plants, including Cordaites.	500	152	Glass Mountains	Permian rocks form the Glass Mountains, an upland of northeastward-trending cuestas whose scarps face southeast. In general, the Capitan beds make the high crests and the rugged northeastward-trending back slopes. The Wolfcamp beds make the outer southern foothills.	Epoch of Marathon orogeny	Gentle folding at end of Permian time.
		—Erosional unconformity—						
		Capitan limestone: Massive dolomite of probable reef origin, with interfingering members in the east of thin-bedded lagoonal dolomite and in the west of sandy strata with open-sea type of fossils. Contains *Fusulina elongata*, calcareous algae, and other fossils much altered by diagenesis.	3,000	914				Broad uplift of Glass Mountains region. Reef deposition.
		Word formation: Siliceous shale (with Radiolana), sandstone, and several members of cherty limestone. Contains *Fusulina elongata, Leptodus, Richthofenia,* and *Waagenoceras.*	[a] 1,500	457				
		Leonard formation: Siliceous shale, sandstone, conglomerate, and limestone, the limestone in beds 1 to 100 feet (0.3 to 30 meters) thick. Contains *Richthofenia; Leptodus; Productus iwesi,* and *Perrinites.*	[b] 1,800	549				Relatively rapid erosion of Marathon folds. Deposition of conglomerate and finer clastic materials as a lens along their north base.
		Hess formation: Massive limestone in west, passing eastward into a great mass of thin-bedded dolomitic limestone. The massive limestone may be a reef. Contains small *Fusulina;* primitive *Richthofenia,* and *Scacchinella.*	[c] 100	30				Limestone deposition. Slight recurrence of movement.
		—Slight unconformity—						
		Wolfcamp formation: Clay shale, with thin limestone beds, overlapping westward on the older formations, where it contains thick, coarse basal conglomerate. Contains *Schwagerina, Teguliferina,* primitive members of *Leptodus* group, and *Uddenites* (in lowest member), a fauna evidently transitional from Pennsylvanian to Permian.	700	213				
		Marked angular unconformity, whereby Wolfcamp beds overlap westward across a region of little-deformed upper Pennsylvanian rocks to highly disturbed and profoundly eroded rocks at the southwest end of the mountains.						Culmination of Marathon diastrophism, with overthrusting of older rocks northward across higher Pennsylvanian. Overthrust cuts across earlier folds but is itself somewhat warped. Continuance of folding indicated by Gaptank conglomerates. First overthrusts probably folded at this time. Time of the exotic blocks, probably representing first mountain making in Marathon region. Time of overthrusts of southern part of area, which have since been folded.
	Pennsylvanian.	Gaptank formation: Thin fossiliferous limestones interbedded with clay shale, sandstone, and coarse conglomerates. Middle and upper parts contain *Triticites, Schistoceras,* and numerous other upper Pennsylvanian fossils. Lower part contains *Fusulinella, Chaetetes,* and *Chonetes mesolobus.*	1,800	549		Lowlands, much covered by gravel.		
		Haymond formation: Upper part composed of thick arkose beds, with one or more layers of exotic blocks (a few inches to 100 feet (30 meters) across, of rocks of all ages from pre-Cambrian to Pennsylvanian). Lower part of thinly interbedded sandstone and shale. Several zones of Pennsylvanian plants, possibly Pottsville.	2,500	762				
		Dimple formation: Thin and thick-bedded limestone, interbedded with shale. Contains a few goniatites and brachiopods of Pottsville age.	800	244		One of chief ridge makers of Marathon Basin. Low narrow hogbacks.		Deposition of great lenticular mass of Flyschlike material.
		Tesnus formation: In its greatest development (in southeastern part of area) is a vast series of alternating quartzitic thick-bedded sandstones and shale, with a predominantly shaly member in the lower part. Thins out to a few hundred feet and becomes all shale to northwest. Contains poorly preserved plants whose age is uncertain.	7,000	2,133		Low rugged areas and rocky ridges.		
		Slight erosional unconformity and marked northward overlap on Caballos novaculite.						
Devonian(?).		Caballos novaculite: Novaculite members, interbedded with thinly layered chert. Few fossils.	400	122	Marathon Basin.	Chief ridge makers of the Marathon Basin. The novaculite makes white outcrops, and the Maravillas chert forms dark-colored exposures.	Deposition in a geosyncline.	
Ordovician.	Upper.	Maravillas chert: Predominantly black bedded chert above; predominantly limestone below. Boulder beds locally at base. Upper Ordovician graptolites, brachiopods, Bryozoa, etc.	350	107				
	Middle.	Woods Hollow shale: Clay shale, with thin limestone and sandstone beds. Middle Ordovician graptolites, brachiopods, Bryozoa, etc.	500	152		Lowland.		First diastrophism, indicated by occurrence of boulders as old as Cambrian in Woods Hollow and Maravillas formations.
		Fort Pena formation: Massive sandy limestone, bedded reddish chert, with conglomerate in lower part. Middle (?) Ordovician graptolites.	150	46		Low discontinuous ridges.		
	Lower.	Alsate shale: Green shale, with some limestone beds in south. Lower Ordovician graptolites.	800	244		Lowlands and low ridges.		
		Marathon limestone: Flaggy limestone, with shale partings, and many beds of flagstone conglomerate, containing Lower Ordovician graptolites. Near middle is a bed of dolomite with cephalopods, gastropods, sponges, etc.						
Cambrian.	Upper.	Dagger Flat sandstone: Thick-bedded saccharoidal brown sandstone, interbedded with shale in upper part; Upper Cambrian trilobites.	300+	91+				

[a] Thins to 500 feet (152 meters) in east.

[b] Thins to 300 feet (91 meters) in east.

[c] Thickens to 2,100 feet (640 meters) in east.

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are entirely the result of differential erosion, in an arid climate, of rocks of varying degrees of resistance. A view from Horse Mountain, the highest peak in the Marathon Basin, is shown in Plate 1, *B*.

The structural features of the Paleozoic rocks in the Marathon Basin resemble those in the Ouachita and Appalachian Mountains and like them were formed toward the end of the Paleozoic era. They consist of sharp folds, striking northeast and generally overturned northwestward. There are numerous faults, and in places the strata have been overthrust for many miles northwest from their original positions. The present miniature mountain ridges are the stumps of lofty mountains, which have been partly renewed as a result of Cenozoic uplift and erosion in the Marathon dome. The area in which these old features are exposed is only a part of the region involved in the Paleozoic folding. The disturbed rocks extend for many miles on both sides under the cover of the Cretaceous strata.

The Paleozoic rocks of the Marathon dome aggregate 20,000 feet (6,096 meters) in thickness and represent Cambrian, Ordovician, Devonian (?), Pennsylvanian, and Permian time. (See accompanying table.) The culmination of the Marathon orogeny came before Permian time, and rocks of that age lie unconformably on the older beds in the Glass Mountains.

Pre-Carboniferous.—The pre-Carboniferous rocks at Marathon consist of thin layers of limestone, alternating with much shale, sandstone, and conglomerate. There are also several siliceous formations, including the Devonian (?) novaculite (pl. 1, *B*), whose white outcrops are one of the most prominent features of the area. The Ordovician rocks at Marathon contain graptolites and linguloid and oboloid brachiopods, animals which lived in an environment of turbid water. By contrast, the Ordovician rocks not far to the northwest, in the region of El Paso, contain cephalopods, gastropods, orthoid brachiopods, and sponges, which appear to have been adapted to a clear-water environment. The contemporaneity of part of these formations is proved by local occurrences of the clear-water fossils in the Marathon section—for example, in the layer of dolomite in the Marathon limestone, which contains fossils like those of the El Paso limestone at El Paso.

Carboniferous.—The strata of Pennsylvanian age have an aggregate thickness of about 12,000 feet (3,658 meters) and are nearly all clastic. The lower part has a strong resemblance to the Flysch of the Alps, particularly the Tesnus and Haymond formations, which are a great series of alternating sandstones and shales, with few fossils other than poorly preserved plant

remains. Microscopic study shows that many of the sandstones are composed of fragments of crystalline and metamorphic rocks. Beginning at the end of the Haymond epoch (with the time of the exotic blocks), there was a great change in sedimentation. The materials above the Haymond were derived mostly from the older rocks of the geosyncline and include many beds of conglomerate, some of whose fragments are of great size, composed of earlier Paleozoic rocks. These upper beds contain rather abundant marine fossils of middle to upper Pennsylvanian age.

The pre-Permian rocks at Marathon furnish an interesting contrast to those exposed near Van Horn and El Paso, only a few hundred miles away. Most of the strata there consist of limestone in thick or massive beds, whose fossils give indication of a clear-water environment. These differences are thought to represent the difference between a foreland and a geosynclinal facies. The Marathon region was close to the old hinterland of Llanoria, from which, up to late Haymond (middle Pennsylvanian) time, most of its sediments were derived.

Relations between Pennsylvanian and Permian.—West of Marathon are low hills of steeply dipping shales and conglomeratic limestones containing upper Pennsylvanian fossils. These beds are assigned to the Gaptank formation (14).[3] To the south are hills and ridges of novaculite and chert (pre-Carboniferous) overthrust on the Gaptank strata with nearly flat fault contact, as shown in Figure 4. North of the railway are several isolated areas of the pre-Carboniferous rocks, surrounded by Pennsylvanian beds, which are believed to be remnants of the overthrust sheet. This overthrust, called the Dugout Creek overthrust, has an observed displacement of nearly 6 miles (9.6 kilometers) to the northwest. In the foothills of the Glass Mountains, to the north, and in their westward extension the Permian series begins with 300 to 400 feet (91 to 122 meters) of coarse conglomerates (Wolfcamp formation) gently tilted to the north, which overlie with angular unconformity the highly contorted and inclined Pennsylvanian beds. The Dugout Creek overthrust is therefore older than the Permian and was probably formed late in Pennsylvanian time.

Permian series.—The strata of Permian age (see p. 3, footnote 2) constitute the Glass Mountains, on the northwest and north sides of the Marathon Basin. From points near Marathon the range presents its most imposing appearance, with steep scarps surmounting a pedestal of sloping plains. The mountains rise 1,000 to 2,000 feet (305 to 610 meters) above their surroundings. About midway along the front of the range, north of Mar-

[3] Numbers in parentheses refer to bibliography, p. 38.

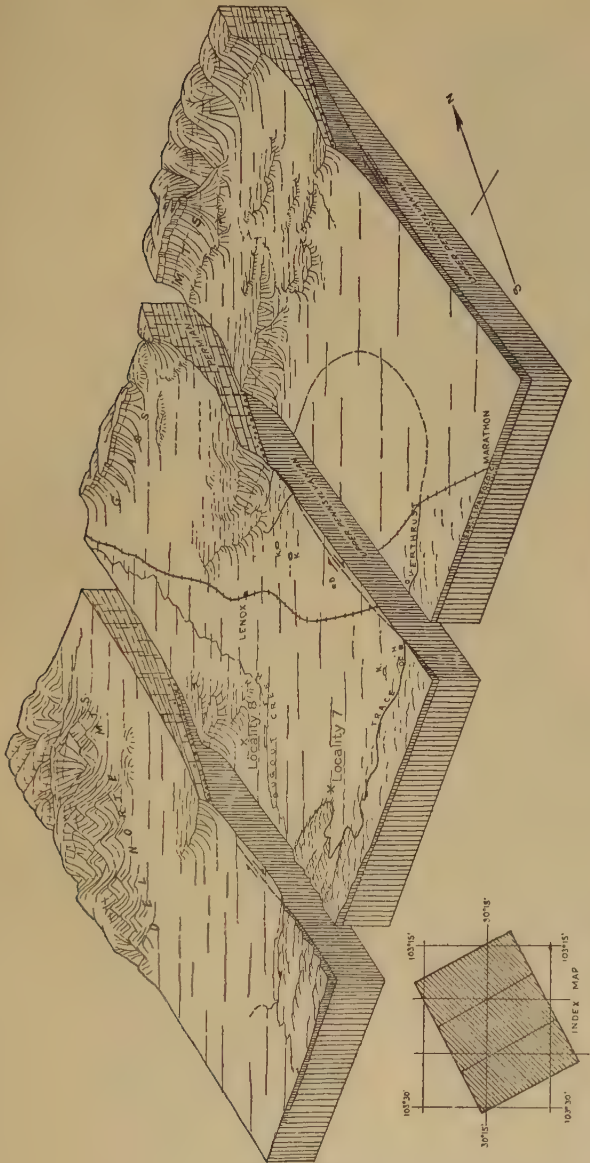


FIGURE 4.—Block diagram of Dugout Creek area, showing trace of Dugout Creek overthrust

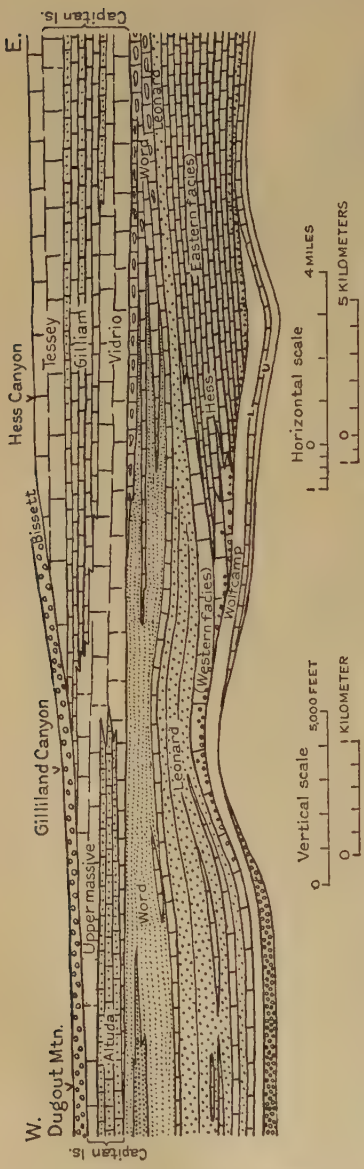


FIGURE 5.—Stratigraphic diagram showing variations in the Permian rocks of the Glass Mountains along the strike of the range

athon, the bald knob of Iron Mountain, a stock of intrusive syenite, stands between the plain and the escarpments of stratified rock. West of Iron Mountain the high broken crests of the range, capped with crags of dolomite, attain an altitude of 6,500 feet (1,981 meters). Lower cuestas several miles south of the main escarpments hide their bases from view at Marathon and form the northern boundary of the Marathon Plain. East of Iron Mountain the escarpments of the range are less imposing, for their summits diminish in height, and the capping cliffs give place to thinner ledges.

Except for the highest members, the Permian rocks of the Glass Mountains are all marine. The total thickness of beds exposed is nowhere less than 6,000 feet (1,829 meters). The most prominent members of the system are limestones, which stand in cliffs and escarpments. In the lower half of the section these are interbedded with shales, siliceous shales, and sandstones, which make slopes or valleys. The siliceous shales contain Radiolaria. The most striking feature of the stratigraphy in the Glass Mountains is the great lateral variation in thickness and lithology of the beds. In the eastern part of the range the rocks are nearly all limestone, and in the western part about half of them are clastic beds. (See fig. 5.)

The marine Permian fauna of the Glass Mountains is of Guadalupian type. Fossils of this sort are almost entirely confined to the western Texas region in North America, but in the Old World similar fossils are found in Permian rocks along the zone of the Tethyan geosyncline. Most of the other marine faunas in this country are more or less impoverished or at least

FIGURE 6.—Structural map of the Marathon Basin showing general relations. Note the northeasterly trend of the folds and the northwesterly cross folding, represented by an arch crossing the Marathon and Dagger Flat anticlinoria and by a downwarp between Tesnus and Gap Tank. The Dugout Creek overthrust is brought to the surface by the cross folding. Dotted line shows route of excursion; numbers refer to localities described in text

do not contain so great a variety of life as the Guadalupian fauna. The Guadalupian, as known in the Glass Mountains, includes many Foraminifera (especially fusulinids of large size), sponges, corals, echinoids, crinoids, a fine assemblage of ammonoids, some nautiloids, pelecypods, and gastropods, profuse bryozoans, and a whole host of brachiopods, in which the

Productus group predominates. The brachiopods also include several strange aberrant types, such as *Leptodus*, *Scacchinella*, *Teguliferina*, and *Richthofenia*. The last three are so strangely modified that they look more like corals or rudistids than brachiopods. Many of the productids are elaborately spinose. In the higher parts of the Glass Mountains section, the massive limestones appear to have been constructed by reef-making algae whose remains are numerous in the rock. The fossils in many of the layers have been very perfectly replaced by silica, so that their delicate external and internal structures can be revealed for study by the careful use of acid.

EXCURSIONS NEAR MARATHON

A general view of the Marathon region is had from the summit of the ridge 2 miles (3.2 kilometers) east of the village. The ridge is composed of nearly vertical novaculite (Caballos formation, Devonian?) and black chert (Maravillas formation, Upper Ordovician). To the east, scarps of nearly horizontal Lower Cretaceous limestone form the sky line; to the south are other similar chert and novaculite ridges; to the southwest is Santiago Peak, an intrusive mass of syenite 30 miles (48 kilometers) away, followed to the north in succession by Elephant Mountain, a level-topped mesa of lava west of the Marathon dome, and the Del Norte Mountains, the eastward-facing scarp of Cretaceous limestone that bounds the Marathon Basin on the west. To the north lie the Glass Mountains, with the intrusive mass of Iron Mountain near their middle.

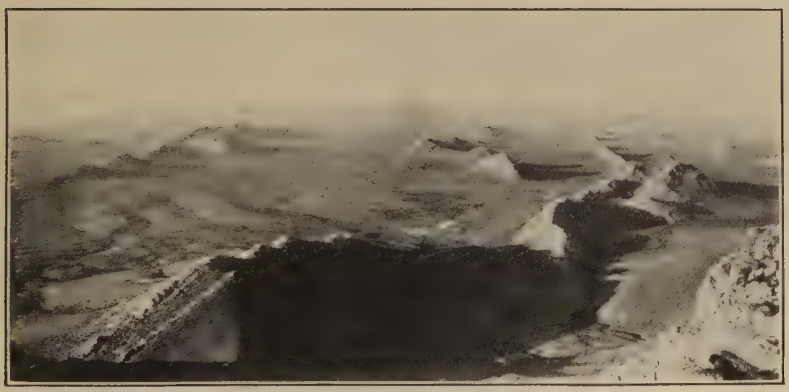
Fossil beds in the Leonard and Word formations (lower and middle Permian in the Glass Mountains.—The localities are 10 to 15 miles (16 to 24 kilometers) north of the town of Marathon, in the region of Hess and Gilliland Canyons.

1.[4] The road to the Glass Mountains goes north from Marathon across a gravel-sheeted plain for 10 miles (16 kilometers). Above the plain rise low novaculite ridges. The Glass Mountains are entered at the Hess ranch, 10 miles (16 kilometers) from Marathon, where the ridges near the road belong to limestones of the Hess formation, of reef and lagoon origin. These limestones also make Leonard Mountain, west of the ranch. The road goes northward from the ranch to the region near the head of Hess Canyon, where all the ridges are made up of the Word formation. (See fig. 7.)

[4] Numbers refer to localities shown on general map of Marathon region, Figure 6.

A. HOUSETOP MOUNTAIN, 20 MILES EAST OF MARATHON

View from the south, showing angular unconformity between limestones of the Comanche series and sandstones of the Tesnus formation. Photograph by Philip B. King.



B. VIEW SOUTHWESTWARD FROM THE SUMMIT OF HORSE MOUNTAIN, THE HIGHEST PEAK IN THE MARATHON BASIN

Showing ridges of Caballos novaculite and lowlands of Tesnus sandstone. Photograph by Philip B. King.

Silicified fossils are extremely abundant in the Word limestones here, including the following, identified by R. E. King (16, p. 10):

Fusulina of elongata type.
Various gastropods and nautiloids.
Enteletes dumblei.
Meekella attenuata.
Meekella skenoides.
Productus multistriatus.
Hustedia meekana.
Marginifera opimus.
Marginifera popei.
Aulosteges guadalupensis.
Prorichthofenia permiana.
Leptodus nobilis americanus.
Spirifer pseudocameratus.
Spiriferina laxa.
Squamularia guadalupensis.

2. Returning past the Hess ranch, the route passes between Leonard Mountain and Iron Mountain. Iron Mountain is composed of intrusive syenite, and Leonard Mountain of massive lenticular reef limestones, which stand in great cliffs. At the west end the reef beds thin out and interfinger with shaly strata. The reef beds have been included in the Hess formation, but the

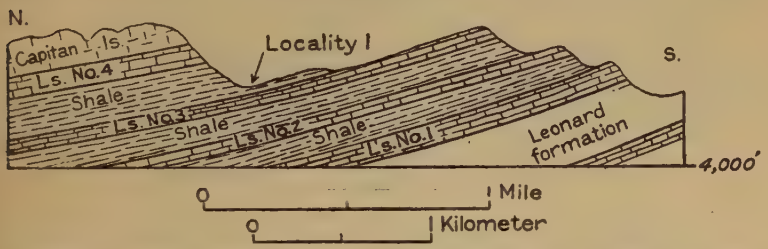


FIGURE 7.—Section across outcrop of Word formation at locality 1, Glass Mountains, showing position of limestone members. Collections are made in bed 3

shaly beds on the west are of the facies of the Leonard formation, proving that there is more or less interfingering between the two formations. The west end of Leonard Mountain will be ascended on the excursion. Here may be studied the face of the reef and its outer edges, as well as the intercalated shaly beds, which were deposited in the open sea in front of the reef.

The reef beds are massive gray limestones, crowded with algae, corals, bryozoans, and sponges, with which are associated reef-adapted brachiopods as *Scacchinella*, *Richthofenia*, *Geyerella*, and thick-shelled species of *Productus*. The rock is full of massive and abraded crinoid columns as much as 1 inch (2.5 centimeters) in diameter. The beds between the reef layers are siliceous shales and thin beds of granular limestone, with a different faunal association, adapted to growth on the sea bottom at the outer margins of the reefs. Here are such fossils as *Strophalosia* and other thin-shelled or spinose brachiopods, the

ramose fronds of such Bryozoa as *Fenestella*, and a few *Fusulina*. The shales contain Radiolaria.

Pennsylvanian stratigraphy and structure east of Marathon.—Leaving Marathon, the route goes due east across gravel-covered plains for the first 15 miles (24 kilometers). Low ridges of novaculite rise above it to the south and of Dimple limestone to the north.

3. About 16 miles (26 kilometers) east of Marathon the highway follows a water gap across the Dimple limestone ridge, and a complete section of this formation is presented in the road cuts. The formation is about 800 feet (244 meters) thick and consists of alternating layers of shale and limestone. The few fossils collected from it indicate very early Pennsylvanian age. Just beyond this exposure the route leaves the main

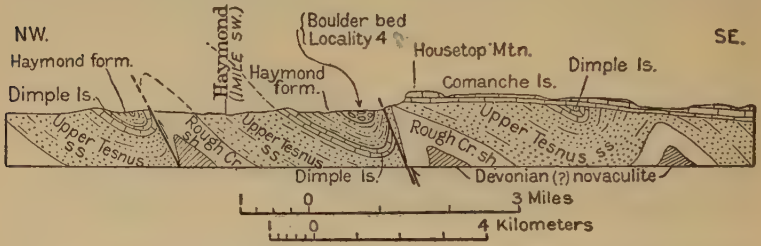


FIGURE 8.—Section past the summit of Housetop Mountain along a line parallel to and about 1 mile (1.6 kilometers) northeast of the Southern Pacific Railroad. Shows structural position of exotic blocks in upper part of Haymond formation at locality 4

highway and proceeds on a graded road across a dissected country underlain by strata of the Tesnus and Haymond formations.

4. At the west base of Housetop Mountain, 20 miles (32 kilometers) east of Marathon, are exposures of upper Haymond exotic blocks. Housetop Mountain itself is capped by limestones of Comanche age (Lower Cretaceous) which rest with a striking angular unconformity on the tilted Pennsylvanian strata. (See pl. 1, *A*, and fig. 8.)

The exotic blocks are in the upper part of the Haymond formation and lie in beds of shale and arkosic sandstone. They consist of cobbles of pre-Cambrian crystalline rocks and small to large masses of earlier Paleozoic limestones, sandstones, and cherts. Some of the limestone and novaculite blocks are more than 100 feet (30 meters) across. The material is thought to have been an original deposit, carried in, in a manner not yet satisfactorily explained, from the first mountains to be formed

in the Marathon region. It may have been deposited in alluvial fans or mud flows at the front of rising overthrust sheets, but transportation by glacial or floating ice has been suggested. (See fig. 8.)

Early Paleozoic strata south of Marathon.—On the road southward from Marathon to the Terlingua quicksilver mines exposures of the earlier rocks can be studied.

5. At the picnic grounds at old Fort Pena Colorada, 5 miles (8 kilometers) southwest of Marathon, are excellent exposures of the Maravillas chert (Upper Ordovician) and the Caballos novaculite (Devonian?). (See fig. 9.)

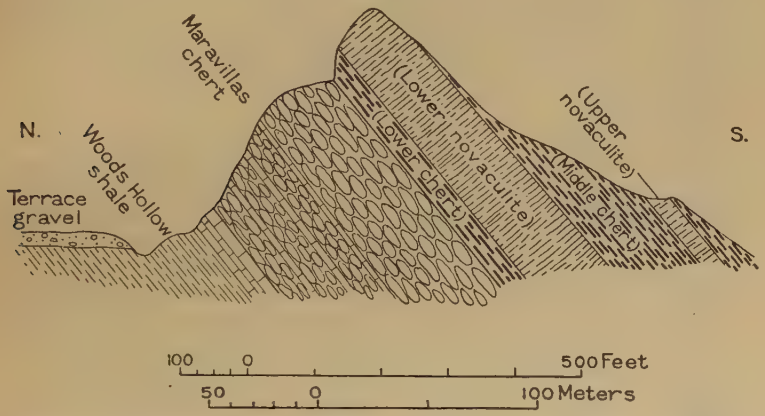


FIGURE 9.—Section at picnic grounds at old Fort Pena Colorada (locality 5)

6. Three miles (4.8 kilometers) farther west, on a branch road along Alsate Creek and the hills to the west of it, are excellent exposures of the Dagger Flat sandstone (Upper Cambrian), the Marathon limestone and Alsate shale (Lower Ordovician), the Fort Pena formation (Middle? Ordovician) and the Woods Hollow shale (Middle Ordovician). (See fig. 10.)

Overthrusts and unconformities west of Marathon.—The old road westward from Marathon to Alpine for the first 3 miles (4.8 kilometers) crosses steeply inclined Ordovician and Devonian (?) strata. Then the trace of the Dugout Creek overthrust is passed, and 4 miles (6.4 kilometers) west of Marathon are outcrops of upper Pennsylvanian shale and thin limestone. The relations are more clearly revealed farther on. (See fig. 4.)

7. About 7 miles (11 kilometers) west-southwest of Marathon is the east end of a range of novaculite hills. The novaculite and chert in these hills rest with nearly flat overthrust contact

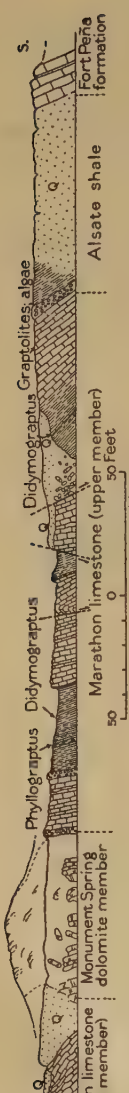


FIGURE 10.—Section on Alsate Creek 6 miles (9.6 kilometers) southwest of Marathon (locality 6). By Josiah Bridge and C. L. Dake

on the upper Pennsylvanian, which crops out lower on the slopes. (See fig. 11.) Most of the Pennsylvanian is shale, but there are also thin nodular limestone layers which contain abundant fossils. From this and near-by localities have been collected brachiopods, ammonoids, and fusulinids, of which the following is a partial list:

Triticites cullomensis.
Lophophyllum profundum.
Pustula nebraskensis.
Spirifer cameratus.
Prouddenites primus.
Uddenites schucherti.
Pronorites pseudotimorensis.
Schistoceras smithi.
Marathonites hargusi.

King believes that these beds are to be correlated with the Gaptank formation at its type locality, in the eastern part of the Marathon Basin, which is of middle to upper Pennsylvanian age. Baker, on the other hand, maintains that the beds are older and that the fossils have too long a range to be of value. The discussion is of importance, because it determines the age of the youngest beds involved in the overthrusting.

8. About 3 miles (4.8 kilometers) to the northwest of stop 7, at the south base of Dugout Mountain (fig. 12), the lower slopes of the mountain are made up of highly folded and contorted Pennsylvanian limestones and shales. The disturbed attitude is probably related to the overthrusting a short distance to the south. Overlying the Pennsylvanian are gently dipping Permian conglomerates and limestones. The lower cliffs on the mountain consist of conglomerate (Wolfcamp formation), which attains a local thickness of 400 feet (122 meters). Immediately above the conglomerate is an ammonoid zone which contains *Perrinites cumminsi* and *Prothallasoceras welleri*, of early Permian age.

ALPINE TO VAN HORN

Alpine to Marfa (25 miles, or 40 kilometers).—The return to Van Horn will probably be made by a route that leads west from Alpine through the southern part of the Davis Mountains following along or near the line of the Southern Pacific Railroad. South of the road are several prominent peaks; the two nearest Alpine are known as the Twin Mountains, and the higher peak farther west as Paisano Peak. They are the resistant remnants of old volcanic necks. A complicated series of dikes radiate from them and may be seen cutting the volcanic flows in the canyon walls. At Toronto, 8 miles (12.8 kilometers) from Alpine, is a quarry in which a massive flow, resting on agglomerate, is excavated for railroad ballast. West of Paisano Peak the road and railroad pass through a narrow gap known as Paisano

FIGURE 11.—Section southeast from summit of Dugout Mountain showing unconformable relation of Permian to Pennslyvanian and overthrust of earlier Paleozoic across the Pennsylvanian. €, Cambrian; O, Ordovician; D, Devonian (?); TS, Tesnus; HM, Haymond; GT, Gaptank

Pass, used since early pioneer days as a crossing of the Davis Mountains. The pass is the type locality of the dike rock paisanite. After crossing the pass the road descends a few hundred feet into a wide desert plain, which extends to Marfa and far beyond.

Marfa to Valentine (35 miles, or 56 kilometers).—The road crosses a broad desert valley, which contains the southern headwaters of the interior drainage system of Salt Basin. To the north is a wide panorama of the distant irregular crests of the Davis Mountains. At Valentine, in 1931, an earthquake of some intensity caused much damage and demolished several of the frailer buildings. It is believed to have been caused by movement on some of the near-by faults.

Valentine to Van Horn (37 miles, or 60 kilometers).—Near Chispa siding, 12 miles (19 kilometers) from Valentine, is a view of the Tierra Vieja Mountains (known locally as the "rim rock"), to the south—an eastward-tilted mass of Tertiary flows and tuffs, cut by several sills, including one several hundred feet

thick and many miles long, composed of quartz pantellerite, which forms the crest of the range. At the north end of the range these flows and tuffs lie on a thick succession of Lower and Upper Cretaceous rocks, including a great development of the Eagle Ford shale, with numerous ammonoids and other fossils in concretions.

North of the Tierra Vieja Mountains are the Van Horn Mountains, which are conspicuous to the west beyond Chispa siding. They consist chiefly of sedimentary rocks, much faulted and tilted. In the southern part of the mountains are Washita and Fredericksburg limestones and a great succession of the

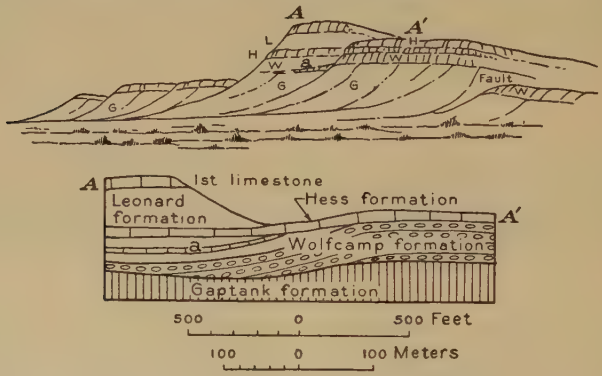


FIGURE 12.—Angular unconformity between Pennsylvanian and Permian at locality 8. At top, sketch of south side of Dugout Mountain as viewed from the southeast. G, Gaptank; W, Wolfcamp; H, Hess; L, Leonard; *a*, locality of Wolfcamp ammonoids. Below, east-west section along face of escarpment between points *A* and *A'*. The complex structure of the Gaptank formation at the base of the escarpment is shown schematically

Lower Cretaceous basal sandstone. Near the north end of the range Permian limestone and pre-Cambrian schist come to the surface.

Between Chispa and Van Horn the bolson plain along the highway east of the Van Horn Mountains is known as Lobo Flat. Here ground water lies somewhat nearer the surface than elsewhere in the plains, and the vegetation is greener. Holes drilled to a depth of 1,000 feet (305 meters) have not reached the base of the bolson deposits.

The east side of Lobo Flat is bordered by ridges of volcanic rocks. The highest peak in the group, Chispa Mountain, is a

stock. North of the volcanic hills are the Wylie Mountains, which were noted before on leaving Van Horn, and there are excellent views from the road of the Permian limestones on its western scarp, resting on the darker pre-Cambrian schists below. Low hills in front of the escarpment are downfaulted masses of Permian limestone.

Within a few miles of Van Horn the Carrizo Mountains, barren jagged hills of pre-Cambrian schist, come into view on the west.

GEOLOGY OF THE VAN HORN DISTRICT

No stop can be made near Van Horn, but a brief account of the geology is presented because so many features are visible from the highway and because the stratigraphic section is the downward continuation of the succession to be studied in the Guadalupe Mountains.[5]

General relations and structure.—The mountains on the west side of Salt Basin near Van Horn consist of nearly flat Paleozoic sedimentary rocks, much broken by faults, the larger of which have outlined the mountain blocks. The largest and highest feature is the Sierra Diablo, 6,700 feet (10,783 meters) in altitude. It faces eastward toward Salt Basin with imposing escarpments several thousand feet high, fringed by great alluvial fans along the base. Here and there along the foot of the mountains are exposures of downfaulted rocks, dragged steeply toward Salt Basin, which show that the eastern margin of the mountains is delimited by faulting. About 30 miles (48 kilometers) north of Van Horn the alluvial fans are traversed by several low straight escarpments, parallel to the mountain front, which are probably very recent fault scarps.

Near its south end the Sierra Diablo is separated from Salt Basin by Beach and Baylor Mountains, which are fault blocks. On the south side, the summits of the Sierra Diablo descend in steps by a succession of east-west fault-line scarps toward the small detritus-filled basin of Eagle Flat. The crests of most of the mountains near Van Horn are made up of Permian limestones which extend nearly if not quite to the base of the mountain to the north, but with the older rocks rising considerably in the southward-facing escarpments.

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[5] The general structural and stratigraphic features of this interesting area have been well described by Richardson (21). Additional data by King are included in this guidebook.

Stratigraphy.—The stratigraphic section is shown in the following table:

Stratigraphic succession in Van Horn area

Age		Formation	Thickness	
			Feet	Meters
Permian.		Massive limestone. A succession, chiefly calcareous, in which are great changes in faunas and lithology within short distances. There is a fine development of thick reef masses.	2,700	823
Angular unconformity, with overlap of Permian across irregular surface of folded beds ranging from Pennsylvanian to pre-Cambrian.				
Pennsylvanian.		Massive limestones, with *Chaetetes milleporaceus* and *Spirifer rockymontanus*, underlain by shales containing pyritized ammonoids. Exposed only near base of escarpment near Figure Two ranch.	800	244
Devonian (?).		Light-colored banded cherts and dark flaggy shales.	150	46
Silurian.		Fusselman limestone. White crystalline massive dolomite, with fossils mostly destroyed by recrystallization.	(?)	(?)
Ordovician.	Upper.	Montoya limestone. Very cherty dolomitic limestone, with brown sandstone at base. Contains *Columnaria*, *Halysites*, *Streptelasma*, *Rhynchotrema*, and *Rafinesquina*.	400	122
	Lower.	El Paso limestone. Thick-bedded mottled limestone with *Piloceras*, *Eccyliomphalus*, *Hormotoma*, and *Ophileta*. Grades down into coarse quartz grits of lower 300 feet (91 meters).	1,000	305

Stratigraphic succession in Van Horn area—Continued

Age	Formation	Thickness	
		Feet	Meters
Angular unconformity of several degrees, by which the Van Horn is in places reduced to a thickness of less than 100 feet (30 meters).			
Upper Cambrian.	Van Horn sandstone. Unfossiliferous red arkose, with conglomerate lenses, several hundred feet of coarse bouldery conglomerate at base, chiefly of red granite and rhyolite porphyry fragments.	700	213
Great angular discordance so that Van Horn rests on the eroded surface of steeply upturned Millican beds and their intrusive bodies.			
Pre-Cambrian.	Millican formation. Red argillaceous sandstone with conglomerate layers, passing downward into a great mass of conglomerate and succeeded by thick-bedded limestones thinly banded by chert. The limestones contain masses of Cryptozoon. All are cut by thick sills of diabase and greenstone and intercalated with flows of basic lava.	3,000	914
	—Overthrust contact; true sequence concealed—		
	Carrizo Mountain schist. Biotite schists and injection gneisses, cut by veins of quartz and pegmatite.	(?)	(?)

To the south the Paleozoic strata lie on the schists and gneisses and to the north on much folded but little altered sedimentary rocks (Millican formation). These two formations are separated by a zone of faulting on which there have been both pre-Cambrian and later movements, and the normal sedimentary contact between them is not exposed. That the Millican is the younger is shown by its lesser metamorphism and by schist fragments in its conglomerates. It is classed as Algonkian (?) and probably may be correlated with the Grand Canyon series of Arizona. The schists crop out west of Van Horn, and the red sandstone member of the Millican is conspicuous along the east face of the Sierra Diablo, 10 miles (16 kilometers) north of Van Horn.

On the eroded surface of these sandstones and the igneous rocks that intrude them rests the Van Horn formation, a great mass of red arkose and coarse conglomerate, regarded as Upper Cambrian, apparently derived from granitic areas now buried beneath the Diablo Plateau.

The fossiliferous record begins with the El Paso (Lower Ordovician), which rests with marked unconformity on the Van Horn sandstone. The Paleozoic beds from this formation upward can be correlated with the several members of the succession at Marathon, but they are of very different facies, as they are foreland deposits laid down in an environment of clear water, in contrast to the geosynclinal deposits at Marathon. The pre-Permian rocks of the region were folded into northeastward-trending arches by late Pennsylvanian diastrophism (during the culmination of the orogeny at Marathon), and the Permian (see p. 3, footnote 2) rests with great unconformity on all the older rocks of the region. On the crests of the arches it overlies the eroded surface of the Cambrian or pre-Cambrian, but in the shallow synclines between are remnants of strata as young as Silurian and Pennsylvanian. One of these synclines runs northeastward under the Baylor Mountains, and another underlies the Permian of the Sierra Diablo near the Figure Two ranch. In places the pre-Permian erosion surface was rugged, and many hills were buried by the younger series in the Baylor Mountains.

The Permian series in the Van Horn region includes most of the strata mapped as Hueco limestone, a prevailingly limestone succession reaching 2,700 feet (823 meters) in thickness, in which there is a great variety of faunal and lithologic facies. During Permian time there was nearly continuous deposition in the region, uninterrupted by crustal movements or incursions of clastic sediments. Elongate barrier reefs are believed to have fringed the embayment of the sea and persisted during the deposition of thousands of feet of strata. The reefs have had a controlling effect on the stratigraphy. In the open sea in front of them flaggy black limestones, siliceous shales, and fine sandstones were laid down; these contain such Guadalupian fossils as *Richthofenia* and *Leptodus*. Immediately behind the reefs lagoon beds of thinly stratified dolomite were deposited, in which fusulinids are extremely abundant; and farther behind, to the west and southwest, limestones with a fauna like that in the Hueco Mountains, including *Omphalotrochus*, *Bellerophon*, *Productus peruvianus*, and *Spirifer condor*. The reefs consist of very massive limestones or dolomites, built of the remains of algae, bryozoans, sponges, crinoids, and other fossils adapted to reef environment. The Permian of the Wylie and Baylor Mountains consists of limestones laid down behind the reefs.

In the Sierra Diablo ledges of lagoon limestone constituting the lower third of the series are succeeded by black limestone and other open-sea deposits outcropping in rounded slopes, which are surmounted by great cliffs of reef limestone. In places there is an abrupt transition from black limestone to reef limestone on the escarpment. At the north end of the Sierra Diablo, 40 miles (64 kilometers) northwest of Van Horn, the reef limestones are overlain by sandstones of the Delaware Mountain formation, a remnant of the thick formation well developed on the east side of Salt Basin.

VAN HORN TO THE GUADALUPE MOUNTAINS

The road from Van Horn to the Guadalupe Mountains (see pl. 2) skirts the west side of Salt Basin for the first 30 miles (48 kilometers). For the first 10 miles (16 kilometers) out of Van

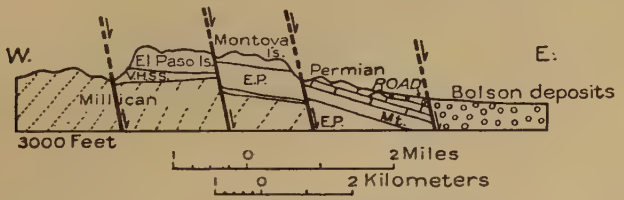

FIGURE 13.—Sketch section across Beach Mountain, north of Van Horn. The road turns to the west around the north side of the mountain and runs nearly parallel to the line of the section. Note unconformity between the Van Horn sandstone (V. H.) and the El Paso limestone (E. P.). Mt., Montoya. Vertical scale twice horizontal

Horn the south end of the flat is in view to the east, with the Apache Mountains beyond it. To the west is Beach Mountain (fig. 13), a rugged mass of El Paso and Montoya limestones (Ordovician), underlain by the red arkose of the Van Horn formation. Some of the foothills nearest the road, 7 miles (11 kilometers) north of Van Horn, are capped by remnants of Permian limestone. Here the road turns to the west up the valley of Sulphur Creek, which separates Beach Mountain from the Baylor Mountains. These mountains, north of the road, are capped by Permian limestones, but strata of Ordovician age are visible in their lower slopes. On the south is the steep north face of Beach Mountain, made up of El Paso limestone (Lower Ordovician) capped by cliffs of the Montoya limestone (Upper Ordovician). Straight ahead in the distance are the escarpments at the south end of the Sierra Diablo. (See fig. 14.) The white cliffs at the top are Permian limestone resting on red sandstone

of the Millican formation (pre-Cambrian), which crops out in smooth slopes. At one place in the escarpment the limestone is underlain by massive ledges of the Van Horn sandstone in a truncated syncline. The truncation of this syncline and the appearance of a thick mass of Ordovician in the 3-mile (4.8-kilometer) interval between the Sierra Diablo and Beach Moun-

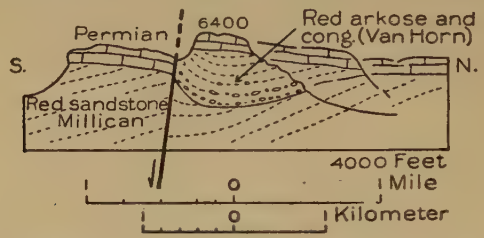

FIGURE 14.—Sketch section at south end of Sierra Diablo, west of Beach Mountain, showing truncation of a syncline of Van Horn sandstone by Permian limestones. Vertical scale twice horizontal

tain are striking illustrations of the unconformity at the base of the Permian.

At 10 miles (16 kilometers) north of Van Horn the road turns north across Sulphur Creek and follows the valley between the Sierra Diablo and the Baylor Mountains. (See fig. 15.) The Sierra Diablo scarp presents a magnificent panorama on the west, with smooth red slopes carved from sandstones of the Millican formation surmounted by cliffs of Permian limestone.

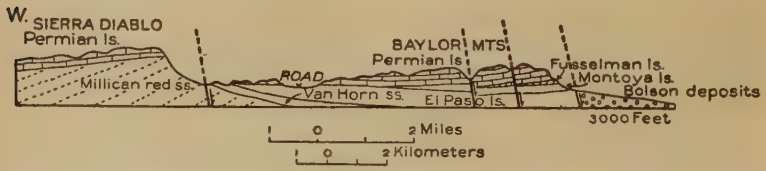

FIGURE 15.—Section across route of excursion at north end of Baylor Mountains. Note overlap of Permian across the Silurian to the pre-Cambrian. Vertical scale twice horizontal

(See pl. 3, *A*.) In the rolling hills of the western part of the Baylor Mountains, east of the road, the same limestone is downfaulted several thousand feet.

About 18 miles (29 kilometers) from Van Horn the end of the Baylor Mountains is passed, and the road comes out on plains which slope eastward to the bottom of Salt Basin. To the north there are salt lakes in the lower part of this flat, sur-

rounded by a wide area of white dunes of unconsolidated gypsum. On the east side of the flat are the low scarps of the Delaware Mountains, composed of alternating benches of limestone and slopes of sandstone and shale, which belong to the Delaware Mountain formation.

West of this point the strata on the scarp of the Sierra Diablo are bent down northward in a monocline, so that Millican red sandstone, which rises high on the slopes to the south, passes beneath the surface. The Permian limestone that forms the top cliff of the mountains on the south descends to the mountain base and north of the monocline makes the outer benches of the mountains. On Victorio Peak, a great projecting mass of bedded strata north of the monocline, the lower limestones are succeeded by black flaggy limestones cropping out in smooth slopes, which are capped by massive cliff-making reef limestone

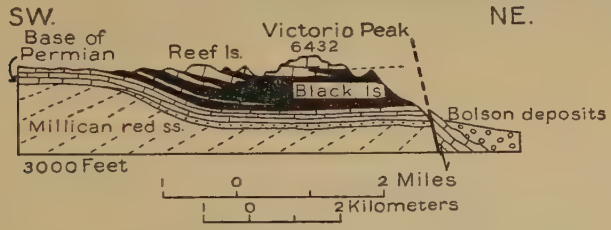

FIGURE 16.—Sketch section across Victorio Peak, nearly parallel to face of escarpment, showing monoclinal structure, fault at edge of Sierra Diablo, and passage from reef limestone on the south to open-sea deposits of black limestone. Vertical scale twice horizontal

that forms the crest of the peak. This reef limestone partly intergrades with the black limestone, as shown on a magnificent scale in the ridges south of the peak. (See fig. 16.)

The road follows the outer edges of the alluvial fans for 15 miles (24 kilometers) northward, with the steep front of the Sierra Diablo a few miles to the west and Salt Basin to the east. At 25 miles (40 kilometers) north of Van Horn there is a large salt lake a few miles east of the road, at the outer margins of the fans. Its position is not in the center of the general basin but on its west side, near the base of the highest scarp, and there is a long upward slope from the lake to the lower ridges of the Delaware Mountains on the east—a relation which implies a recent westward tilting of the basin. The great alluvial fans along the base of the Sierra Diablo likewise suggest movements in the near past.

The great basin extending northward from Van Horn is regarded as a desert, for the average annual rainfall is less than

10 inches (0.25 meter), and ordinary crops will not grow without irrigation. The natural vegetation presents an extensive variety of desert plants, including cacti, yucca, sotol, mesquite, iron wood, ocotillo, maguey, catsclaw, and water willow. On the higher lands are junipers, live oaks, and some piñons, and on the top of Guadalupe Mountain grow pines, spruces, and a few poplars.

About 30 miles (48 kilometers) north of Van Horn, west of the Figure Two ranch, an igneous plug cuts the limestones of the Sierra Diablo and forms a brown conical peak near the base of the escarpment. This and a larger intrusion in a canyon

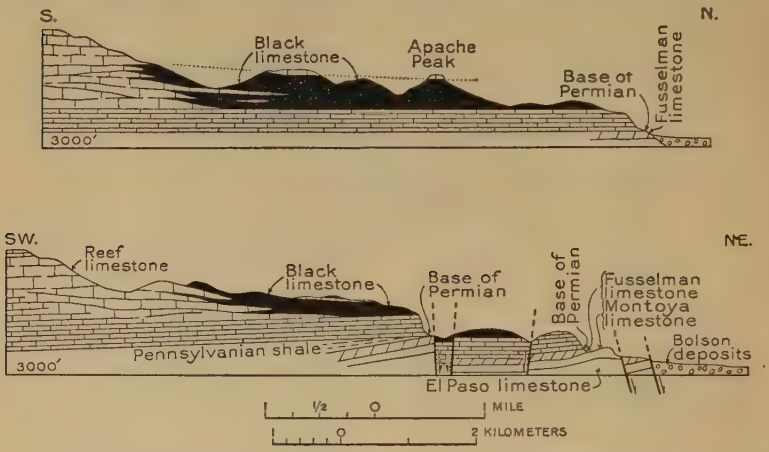

FIGURE 17.—Sections of Sierra Diablo escarpment near Figure Two ranch, north of Van Horn. The left-hand end of each section is the same. Shows northward passage from massive reef limestones into open-sea deposits of black limestone. The lower section shows the ridge on the sky line to the northwest, as seen from the Figure Two ranch

to the west of it have altered the limestones along the contact to white marble but have not disturbed the strata.

South of this place the Permian has the same threefold division as on Victorio Peak—a limestone bench below, slopes of black limestone in the middle, and massive limestone cliffs above. North of the intrusion the black limestone grades abruptly into reef dolomite, and the whole escarpment becomes a succession of crags and cliffs. At the base of the mountains 2 miles (3.2 kilometers) northwest of the Figure Two ranch are exposures of Montoya (Upper Ordovician) and Fusselman (Silurian) limestones lying unconformably beneath the Permian. (See fig. 17.) South of the intrusive plug near the base of the

escarpment are ledges of lower Pennsylvanian limestone, dipping southward with an angular divergence of 5° with the Permian strata.

North of the Figure Two ranch, below the outcrops of the Montoya, the alluvial fans are cut by several low straight escarpments 20 to 30 feet (6 to 9 meters) high, trenched by streams from the mountains. Below these escarpments the streams have deposited great quantities of cobbles and boulders which indicate that the scarps probably mark lines of recent fault movements.

From the Figure Two ranch the highway turns north-northeast across Salt Basin and, leaving the Sierra Diablo behind, goes toward the Guadalupe Mountains, which are plainly in view 30 miles (48 kilometers) away.

Black Flat Top, a mesa west of the road about 50 miles (80 kilometers) from Van Horn, is capped by upper limestone of the Delaware Mountain formation. To the east of the valley in this vicinity is the high westward-facing front of the Delaware Mountains, consisting of the lower dark limestone capped by sandstone. The desert flat which is so wide to the south narrows considerably from this point northward.

At and near the junction of the highway from Van Horn with that from El Paso, 54 miles (87 kilometers) from Van Horn, there are fine views of the south end of the Guadalupe Mountains marked by the high cliff of Guadalupe Point. The principal feature is a general low anticline with westward-dipping strata of the Delaware Mountain formation overlain to the northeast by Capitan limestone constituting the great Guadalupe Point. Just south of the road junction is a prominent ledge of hard massive sandstone in the Delaware Mountain formation dipping southwest under shale, and this sandstone extends northward to the middle slope of the south end of the Guadalupe Mountains. The fact that these formations pass under Guadalupe Point is clearly visible from this vicinity. This point and the mountain extending northward from it consist mainly of a light-colored, very massive limestone (Capitan limestone), of which about 1,800 feet (549 meters) remains. This and the underlying strata contain the remarkable Guadalupian fauna of Permian age (12), comprising nearly 300 species, some of which occur in profusion in certain beds. (Unfortunately this mountain is so high and so far from the road that there will not be opportunity to collect fossils to advantage.) The Capitan limestone is underlain by dark slabby limestone, about 100 feet (30 meters) thick, on sandstone nearly 2,000 feet (610 meters) thick, which in turn lies on dark slabby limestone, the upper part of which is exposed on the west side of the mountain. In the vicinity of Guadalupe

Point these three members constitute the Delaware Mountain formation (19), the limestones of which contain a distinctive older Guadalupian fauna (12, 11).

At the Signal Peak filling station the highway enters the canyon of Arroyo Guadalupe and begins the ascent of a ridge which branches from the east side of the south end of the Guadalupe Mountains and extends southward to the Delaware Mountains, above alluded to. It consists of the sandstone member, some of the harder ledges of which give rise to cliffs of considerable prominence. The rise to the top here is about 900 feet (274 meters) to a divide, beyond which the water runs into Delaware Creek, on the east side of the Delaware Mountains.

To the west is the high east front of the Guadalupe Mountains, with Guadalupe Point at the south end, culminating in El Capitan, the highest point in Texas (altitude about 8,700 feet, or 2,652 meters). (See pl. 4.) This bold front of the massive Capitan limestone capping the upper limestone member of the Delaware Mountain formation is about 3,000 feet (914 meters) high. It extends far to the north but with gradually diminishing altitude and prominence. It is deeply notched by the canyon of Pine Creek, just north of El Capitan; by McKittrick Canyon, 7 miles (11 kilometers) farther north; and by Big Creek and other canyons in New Mexico.

The region from Pine Creek to McKittrick Creek traversed by the highway (except where covered by gravel) and to the east is underlain by the thick medial sandstone member, which extends far up the mountain slope on the west. Its top beds are last exposed in McKittrick Canyon, up which they extend for some distance.

The overlying dark limestone (top member of the Delaware Mountain formation) crops out along the side of the mountain to McKittrick Canyon, where it thickens considerably, apparently by the addition of the lowest part of the Capitan limestone, which becomes a dark slabby limestone. This dark limestone caps the high ridge extending east from McKittrick Canyon and is prominently exposed in the mouth of Big Canyon, where the upper beds contain many fossils showing an admixture of Capitan and Delaware Mountain species. This limestone extends far to the east, as may be seen on the ascent of the ridge by the highway. To the northeast it is overlain by a thick formation of gypsum (Castile, of Permian age) which is younger than the Capitan limestone and directly overlies it in the region near Carlsbad Caverns. This gypsum is in sight in the distance at the top of the ascent, but from that point for several miles the strata are hidden by a thick deposit of gravel (late Tertiary?)

ROUTE MAP, VAN HORN TO CARLSBAD CAVERNS AND EL PASO

Dotted line shows route.

A. PERMIAN LIMESTONE 10 MILES NORTH OF VAN HORN

The Permian here rests unconformably on red sandstones of the Millican formation (pre-Cambrian), which form the smooth slopes below the escarpment. Photograph by Philip B. King.

B. DEPOSITS OF CALCIUM CARBONATE IN CARLSBAD CAVERNS

Photograph by National Park Service.

A. GUADALUPE POINT AND EL CAPITAN

The massive bed is Capitan limestone; the slopes below are sandstones of the Delaware Mountain formation. Photograph by R. T. Hill.

B. SOUTH END OF GUADALUPE MOUNTAINS FROM AN AIRPLANE

Photograph by United States Army Air Service.

constituting a high terrace which extends to the foot of the mountain on the north side of the mouth of Big Canyon.

There is uncertainty as to the relation of the eastern margin of the Capitan limestone in this region and the cause of its absence in the area to the east, where the gypsum lies directly on the black limestone member. The Capitan limestone and underlying strata also change in character to the north and northwest, where they grade laterally into a dirty, slabby limestone with alternating gypsum and red beds (Chupadera formation; 10) carrying a Manzano fauna (Permian) very different from the Guadalupian fauna. This change of character and fauna is attributed to a difference in conditions of deposition, the white limestone with its Guadalupian fauna having accumulated in relatively pure marine waters as a huge algal reef that dammed off the saline and gypsiferous waters during parts of Manzano time.

The relations of these Guadalupian formations as interpreted by Darton and Reeside (11) are shown in Figure 18. Section D shows the probably original thinning out of the Capitan limestone to the east, where it is absent and the upper limestone member of the Delaware Mountain formation is directly overlain by the Castile gypsum. The upper member of the Capitan limestone also thins out and gives place to other strata in the region north of Carlsbad. To the northwest, as shown in sections A and C, the Capitan limestone and underlying beds grade laterally into the Chupadera limestone.

CARLSBAD CAVERNS

The famous Carlsbad Caverns (pl. 3, *B*) are in the east slope of the Guadalupe Mountains about 20 miles (32 kilometers) southwest of Carlsbad, New Mexico. They are of large extent, have considerable depth, and are especially notable for the large chambers and variety of depositional forms, many of them of most impressive size and intricate delicacy. The opening, which is on the mountain side 300 feet (91 meters) above the valley, presents a wide natural arch in which a broad stairway descends into a deep chamber giving access to avenues that ramify through the cavern. The formation is limestone, the member which farther south constitutes the upper part of the Capitan limestone on top of the Guadalupe Mountains. The beds dip to the southeast at a low angle, and the limestone passes under the thick Castile gypsum (Permian) with the relations shown in section B, Figure 18. Fossils of the Guadalupian fauna (Capitan limestone) occur in the limestone, and many have been collected on the old direct road (now abandoned) which climbs

the hill just south of the cavern entrance. The limestone here is about 900 feet (274 meters) thick and is underlain by gypsum, which is penetrated by some of the deeper parts of the caverns (not open to visitors). Undermining by the solution of this underlying gypsum has had much to do with the origin of the

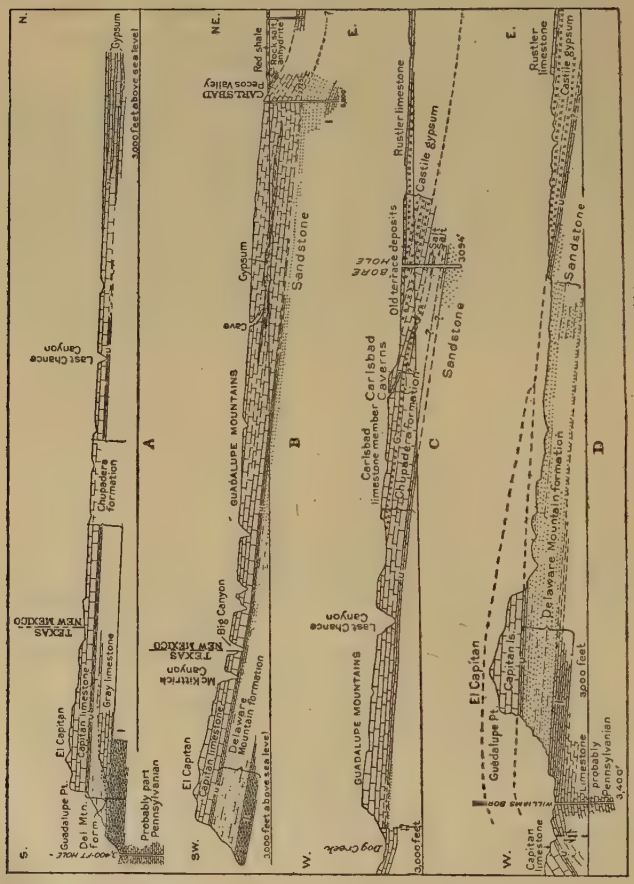

FIGURE 18.—Sections of the Guadalupe Mountains. A, Along center of the range; B, along east side of the range; C, at Carlsbad Caverns; D, through El Capitan

very large rooms in the caverns. Some of these rooms, such as the queen's room and the palace, are most exceptional, the largest one being 4,000 feet (1,219 meters) long, 625 feet (190 meters) wide, and 350 feet (107 meters) high.

All parts of the caverns contain beautiful products of lime deposition, and an abundance of illumination shows off all the

features to great advantage. The distance to be traveled in the caverns is about 7 miles (11 kilometers), and there is considerable climbing to be done, but as the temperature is only 56° F. at all times and the trip is made very slowly it is an easy journey. The upper part of the caverns is a refuge for bats, and it is very interesting to see these animals come out in myriads at dusk. It is estimated that nearly 3,000,000 bats leave the caverns on these nightly forays, always flying south, though the next morning they invariably return from the north. The caverns form a national park under the supervision of a custodian, and guides are provided to take visitors on a route in which all the principal features are visited. No one is permitted to remove any specimens from the caverns.

CARLSBAD CAVERNS TO EL PASO

From the Carlsbad Caverns the road is retraced southward across the Castile gypsum, old terrace deposits, and limestones and sandstones of the Delaware Mountains to the road forks 54 miles (87 kilometers) from Van Horn. Big Canyon and McKittrick Canyon (each 3 miles (4.8 kilometers) from the highway), which cut deep trenches into the east front of the Guadalupe Mountains near the New Mexico-Texas State line, expose the relations of the Capitan limestone to underlying strata.

In Big Canyon the upper black limestone member of the Delaware Mountain formation is exposed. It is a dark slabby rock and contains many fossils, some of them distinctive of the Capitan limestone and others belonging to the fauna of the Delaware Mountain formation (all Guadalupian). On entering the steep canyon it may be seen that the dark member grades laterally into the lower members of the massive Capitan limestone. All the dips are at a low angle to the east.

Progressing south to the fork of the road to the McComb ranch and McKittrick Canyon the highway passes over a plateau of the dark limestone, which it descends about a mile (1.6 kilometers) south of the crossing of McKittrick Creek. (See pl. 2.)

Near and in McKittrick Canyon the underlying sandstone is exposed, and both of these members may be traced some distance up the deep canyon. Here also it is clear that the dark limestone member grades laterally to the west into the base of the massive Capitan limestone, which makes superb walls in the deeper part of the canyon. The sandstones of the Delaware Mountain formation are conspicuous in the rolling country about the McComb ranch and southward, capped by the dark limestone (top) member in the great mountain slope just west.

This limestone member is distinct all along the east and west sides and south end of the mountains in Texas, notably in Guadalupe Point.

Features of the stratigraphy of these beds can be reviewed to some extent in descending the steep grade near the east foot of Guadalupe Point. At the road forks a few miles south the right-hand road is taken to El Paso, 100 miles (161 kilometers) away. It skirts an outlying ridge of Capitan limestone on the west limb of the main anticline of the mountains, which is considerably downfaulted on its west side. Beyond this point the route traverses Salt Basin, whose saline ponds have for many

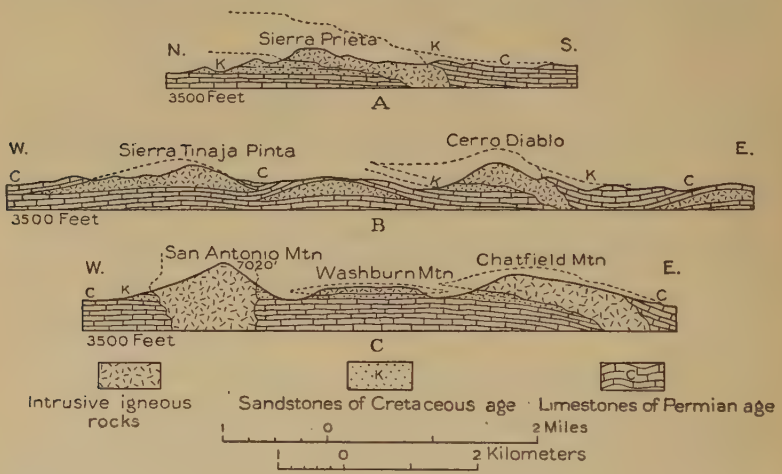

FIGURE 19.—Sections of buttes prominently in view from highway across the plateau to El Paso. A, Sierra Prieta; B, Sierra Tinaja Pinta and Cerro Diablo; C, Cornudas Mountains, on the Texas-New Mexico boundary

years been a source of salt for local use. To the south is the declining north end of the Sierra Diablo, which to the west merges into a wide plateau rising to the crest of the Hueco Mountains. Within a few miles there are outcrops of the Permian limestones that constitute the plateau, and they continue to crop out at intervals far to the west. In the distance on each side are buttes and ridges of intrusive rock, with which are associated small remnants of strata of Lower Cretaceous age which elsewhere have been mostly stripped from the plateau surface. The sections in Figure 19 show some typical occurrences of these strata.

Before reaching the head of Powwow Canyon, through which the road crosses the Hueco Mountains, it passes low rolling hills

of Permian limestones, separated by broad, shallow depressions, some of which are undrained and covered by drifting sand.

At the head of Powwow Canyon the road crosses a divide, and leaving the level Diablo Plateau it descends into a valley through the hilly country that forms the dissected western edge of the Hueco Mountains escarpment. For about a mile (1.6 kilometers) in the upper part of Powwow Canyon there are good exposures and road cuts of limestone of Permian age, which dip gently eastward. Several hundred feet of this limestone is crossed in descending the canyon, and about a mile beyond the head the base of the Permian is reached. In this region there is locally at the base of the Permian (see p. 3, footnote 2) a layer of red shale and conglomerate reaching 150 feet (46 meters) in thickness. These beds are exposed in several ravines on the left (east) side of the road, but they thin out in the overlap southward along the wall of the canyon. Just beyond the red-bed exposures are limestones and marls of Pennsylvanian age, which crop out extensively in the lower part of the canyon. They are truncated by the overlying Permian strata and dip at an angle 5° steeper than the Permian. Some of the relations in and near this canyon are shown in Figure 20.

The canyon bends to the west 2 miles (3.2 kilometers) from its head. On the left (south) are hills of northward-dipping limestones and marls of Pennsylvanian age, well exposed in road cuts; and on the right these strata extend about halfway up the opposite side of the canyon. Here they are overlain by the red beds at the base of the Permian, which crop out in a narrow band and are overlain by Permian limestones that carry *Swagerina beedei*.

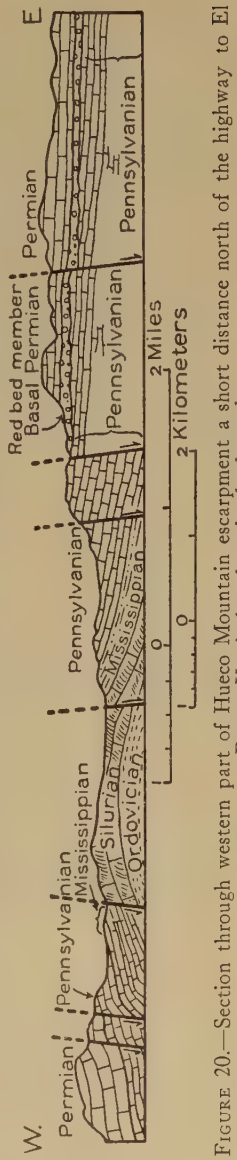

FIGURE 20.—Section through western part of Hueco Mountain escarpment a short distance north of the highway to El Paso. Vertical scale twice horizontal

Five miles (8 kilometers) beyond the head of the canyon the road enters a plain from which rise irregular limestone hills. On the right (north) side of the road 7 miles (11 kilometers) from the head of the canyon are ridges of limestone dipping steeply to the south. The strata nearest the road are at the base of the Pennsylvanian, and the crest of the ridge to the north is made up of sandy limestones of upper Mississippian age, weathered surfaces of which appear yellow or brown from a distance. At this place the structure is anticlinal, and not far north the Fusselman limestone, of Silurian age, is revealed in the axis.

To the west are low knobs and ridges of Permian limestone on both sides of the road for 4 miles (6.4 kilometers). These strata dip gently westward toward the desert plain of the Hueco Bolson, as shown at the left in Figure 18. Some of the outermost of the hills are partly buried in red sand, blown from the low sand hills of the Hueco Bolson, to the west. This wide sandy desert is crossed to El Paso, and for several miles the high ridge of the Franklin Mountains is in view.

SOME GEOLOGIC FEATURES ABOUT EL PASO

The geology in the vicinity of El Paso is described by Richardson (20). The most impressive features are in the Franklin Mountains, a lofty ridge that extends north from the northern edge of the city and is easily accessible by roads and trails. Its west side is mainly a dip slope of heavy beds of limestone with pronounced westerly dip; the east side shows many ridges, irregular lower crests, and buttes, deeply cut by canyons. The range is a typical eroded tilted block mountain of the Basin Range type, which predominates in the southwestern United States. It presents an interrupted succession of strata from pre-Cambrian to Permian, and as they are bare and free from talus or structural complexities they are easily studied. The sections in Figure 21 show the principal features.

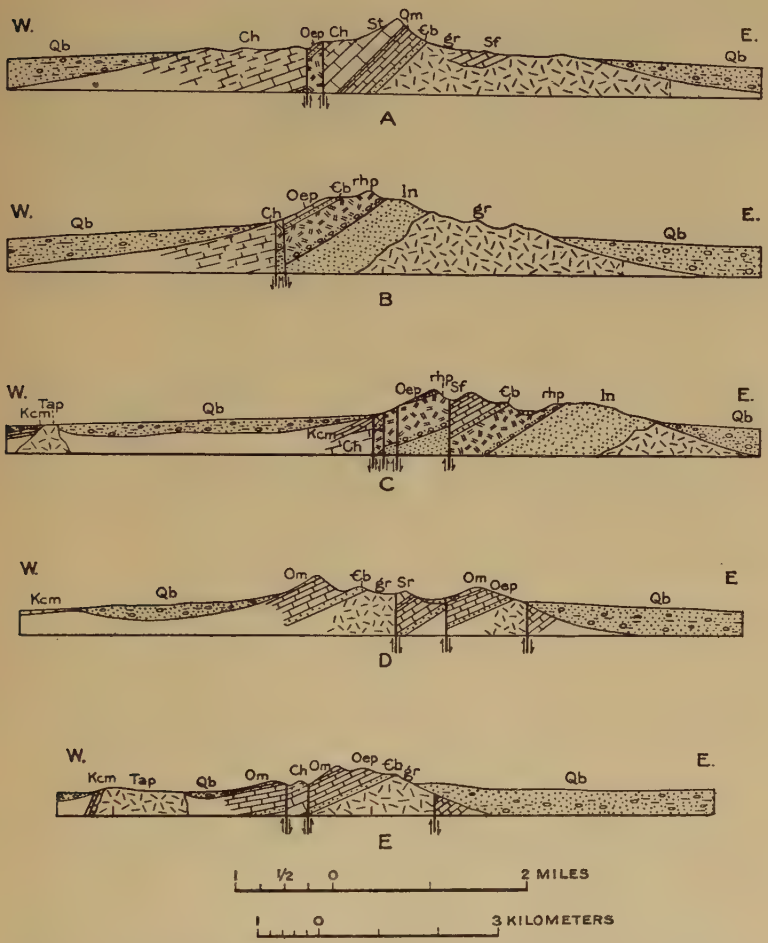

FIGURE 21.—Sections across the Franklin Mountains, north of El Paso. ln, Lanoria quartzite; rhp, rhyolite porphyry; Cb, Bliss sandstone; Oep, El Paso limestone; Om, Montoya limestone; Sf, Fusselman limestone; Ch, limestone, mostly Permian, underlain by Devonian and Pennsylvanian in section A; Kcm, Comanche series; gr, granite; Tap, andesite porphyry; Qb, bolson deposits. (By G. B. Richardson.)

Geologic formations in the Franklin Mountains

Age	Formation	Character	Thickness	
			Feet	Meters
Lower Cretaceous (Comanche).		Limestone, shale, and sandstone.	300	91
Carboniferous.		Permian limestone underlain to the north by a thin limestone of Pennsylvanian age.	1,500	457
Devonian.		Dark impure limestone.	40	12
Silurian.	Fusselman limestone.	Limestone, massive, light and dark.	1,000	305
Upper Ordovician.	Montoya limestone.	Limestone, massive, magnesian.	20–400	6–122
Lower Ordovician.	El Paso limestone.	Limestone, gray, largely slabby; weathers light.	1,000±	305±
Upper Cambrian.	Bliss sandstone.	Sandstone, brown and gray, locally conglomeratic at base.	0–300	0–91
Algonkian (?).		Rhyolite porphyry, mostly red, with agglomerate at base.	1,500±	457±
	Lanoria quartzite.	Quartzite, light and dark, cut by diabase.	1,800+	549+

Granite similar to the pre-Cambrian basement of other regions is also exposed, mostly underlying the Bliss sandstone, but some of it cuts pre-Cambrian and Paleozoic strata.

The Lanoria quartzite with its sills of diabase strongly suggests the Apache group of Arizona. The El Paso limestone here is in its type locality. Its few fossils found to a level within 100 feet (30 meters) of the bottom are regarded as Lower Ordovician. Locally it lies directly on the pre-Cambrian rocks. There are fine exposures of about 1,000 feet (305 meters) of the El Paso limestone and adjoining beds on and near the scenic highway at the south end of the Franklin Mountains. The Montoya limestone, which carries a Richmond fauna (Upper Ordovician), is separated from the El Paso by a hiatus representing much of

Ordovician time. The Fusselman limestone, containing a characteristic *Pentamerus* of Niagara age, represents a small part of Silurian time. It is 1,000 feet (305 meters) thick and constitutes some of the highest summits in the Franklin Mountains. A small wedge of Devonian strata occurs in the northern portion of the range, and also limestone containing Pennsylvanian fossils. The main mass of Carboniferous limestone cropping out along the west slope of the range is, however, of Permian age.

Limestone and shale of Cretaceous age are well exposed near the south end of the Franklin Mountains. The quarries that supply the cement works expose about 90 feet of hard massive gray limestone of the Comanche series (Lower Cretaceous). Higher beds appear on the opposite side of the Rio Grande,

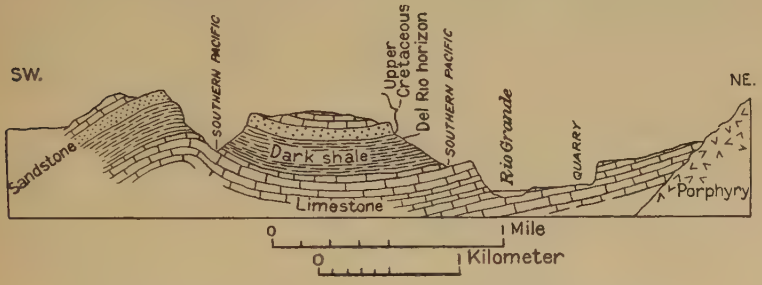

FIGURE 22.—Section on west slope of Cerro de los Muleros

especially along the slopes of the Cerro de los Muleros. (See fig. 22.) These Cretaceous strata are extensively invaded by masses of porphyry.

At several localities in the western part of El Paso there are small outcrops of fissile shale that carry *Inoceramus labiatus*, a Colorado species (Upper Cretaceous), which also occurs on the south side of the Rio Grande.

The thick deposits of gravel and sand of the higher plain north of the Rio Grande are well exposed at many places in the upper part of the city. Wells are reported to have penetrated valley fill to the depth of 2,285 feet (696 meters). Fossil bones found in these Quaternary deposits have been determined as *Elephas columbi*, *Equus complicatus*, and *Tapirus haysii*?.

The mineral cassiterite, or tin oxide, occurs with quartz in the granite 12 miles (19 kilometers) north of El Paso, where it has been extensively prospected.

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